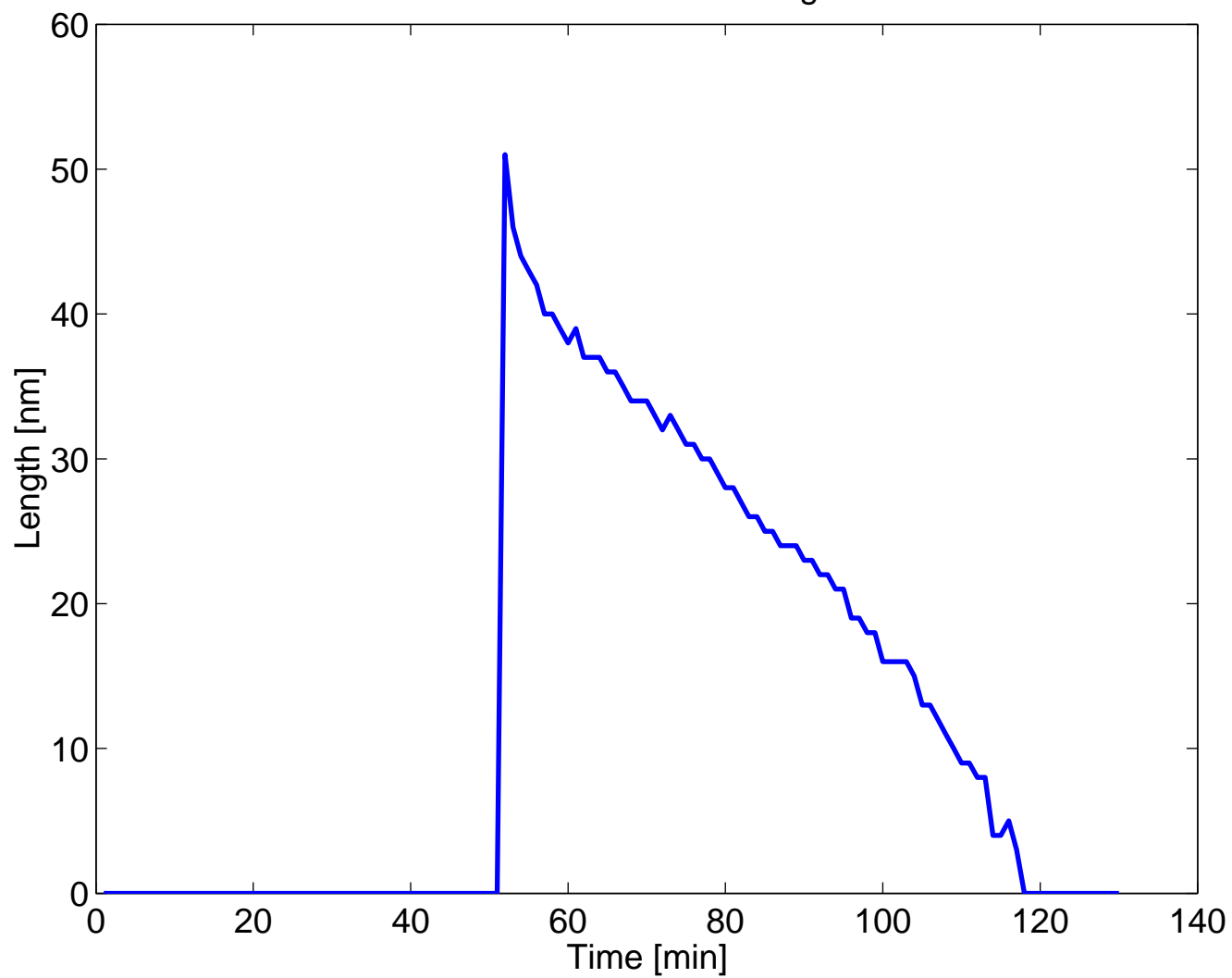
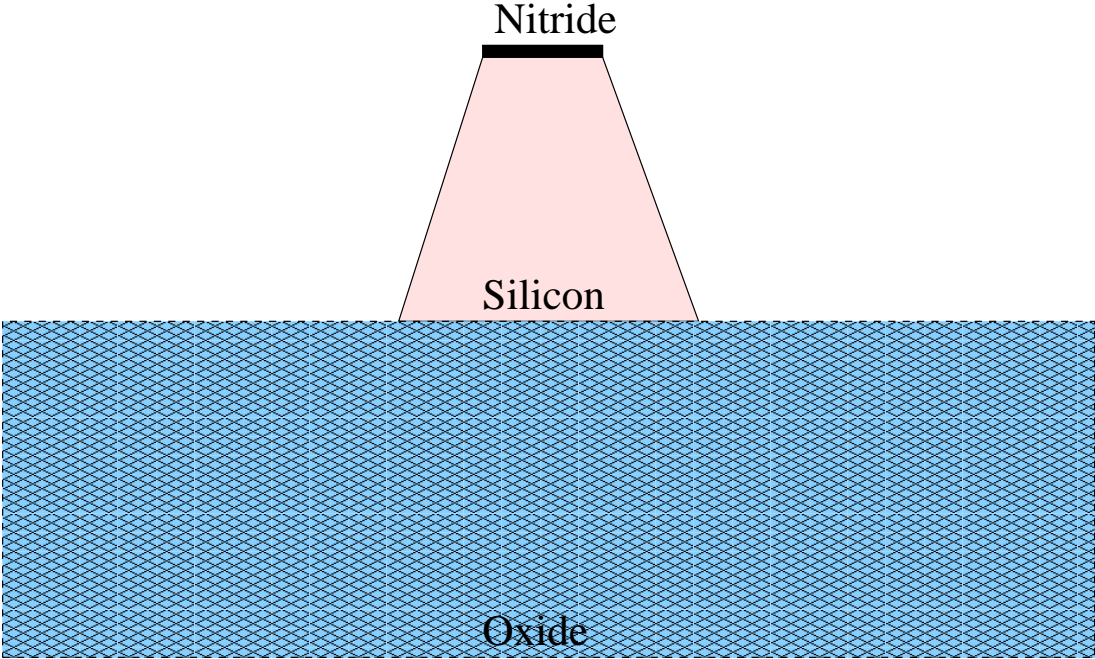


Evolution of the dot length





Optimisation and Simulation of an Alternative Nano-flash Memory: the SASEM device

C. Krzeminski¹, E. Dubois¹, X. Tang², N. Reckinger², A. Crahay² and
V. Bayot²

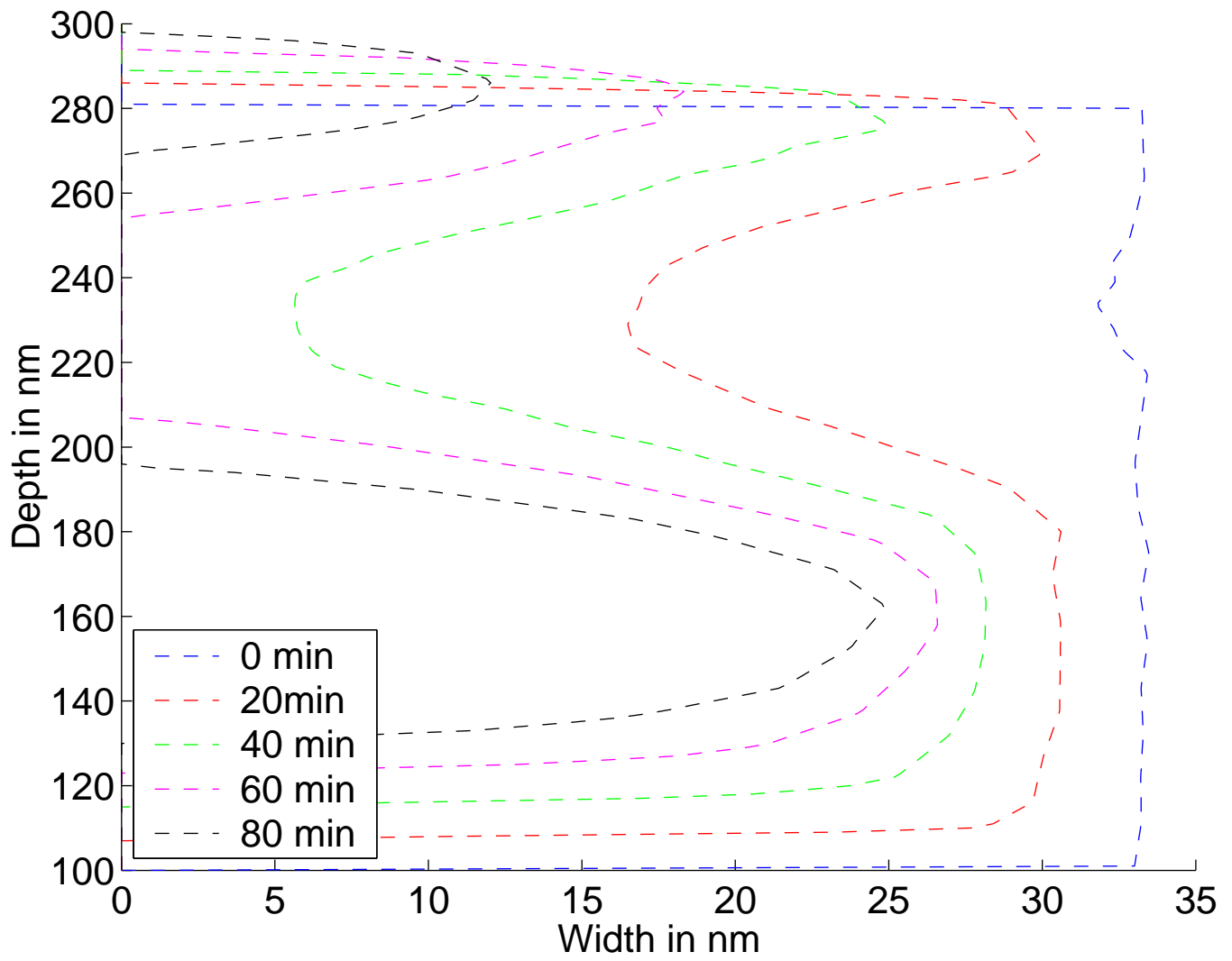
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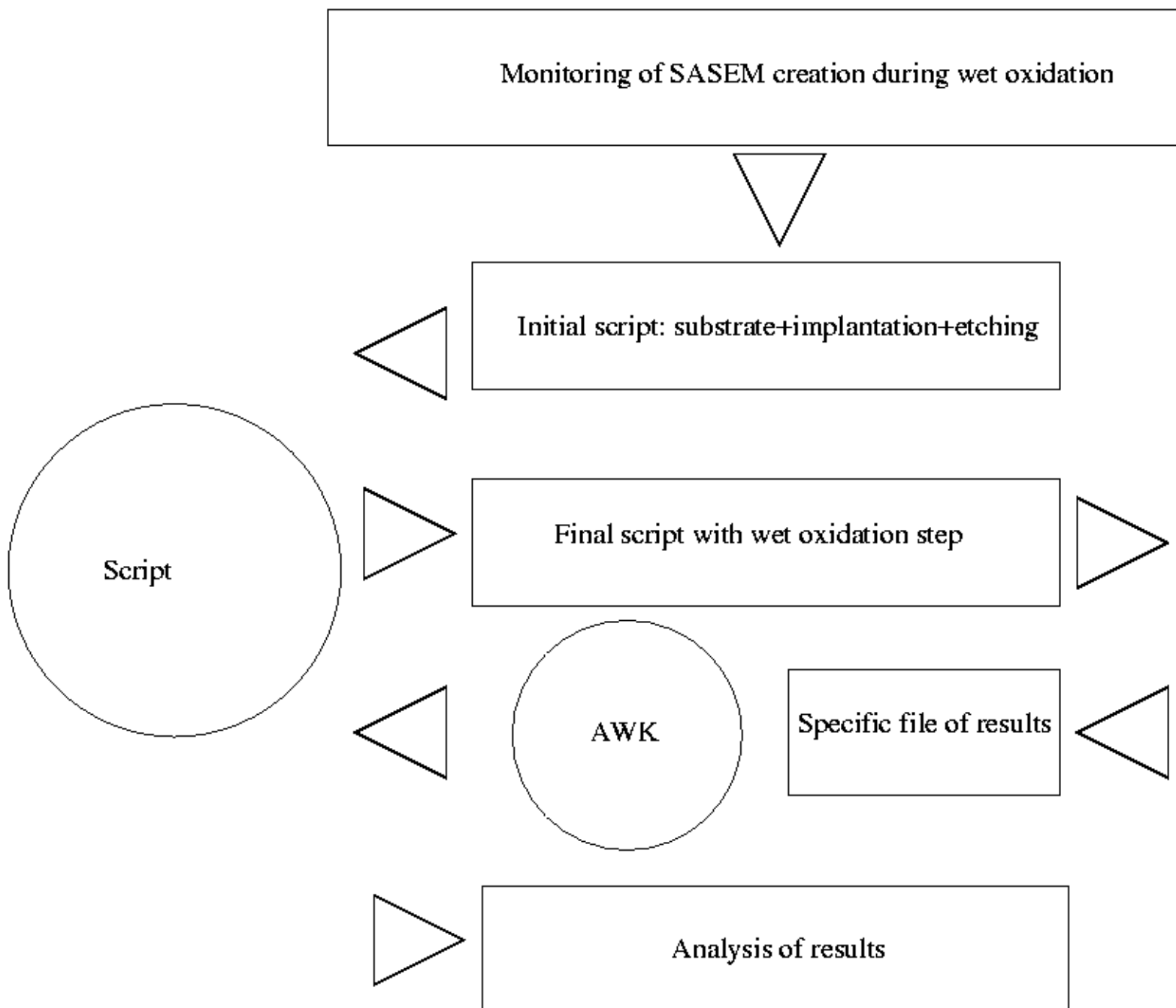
²Microelectronics Laboratory, Université Catholique de Louvain-La-Neuve, Louvain-La-Neuve, Belgium

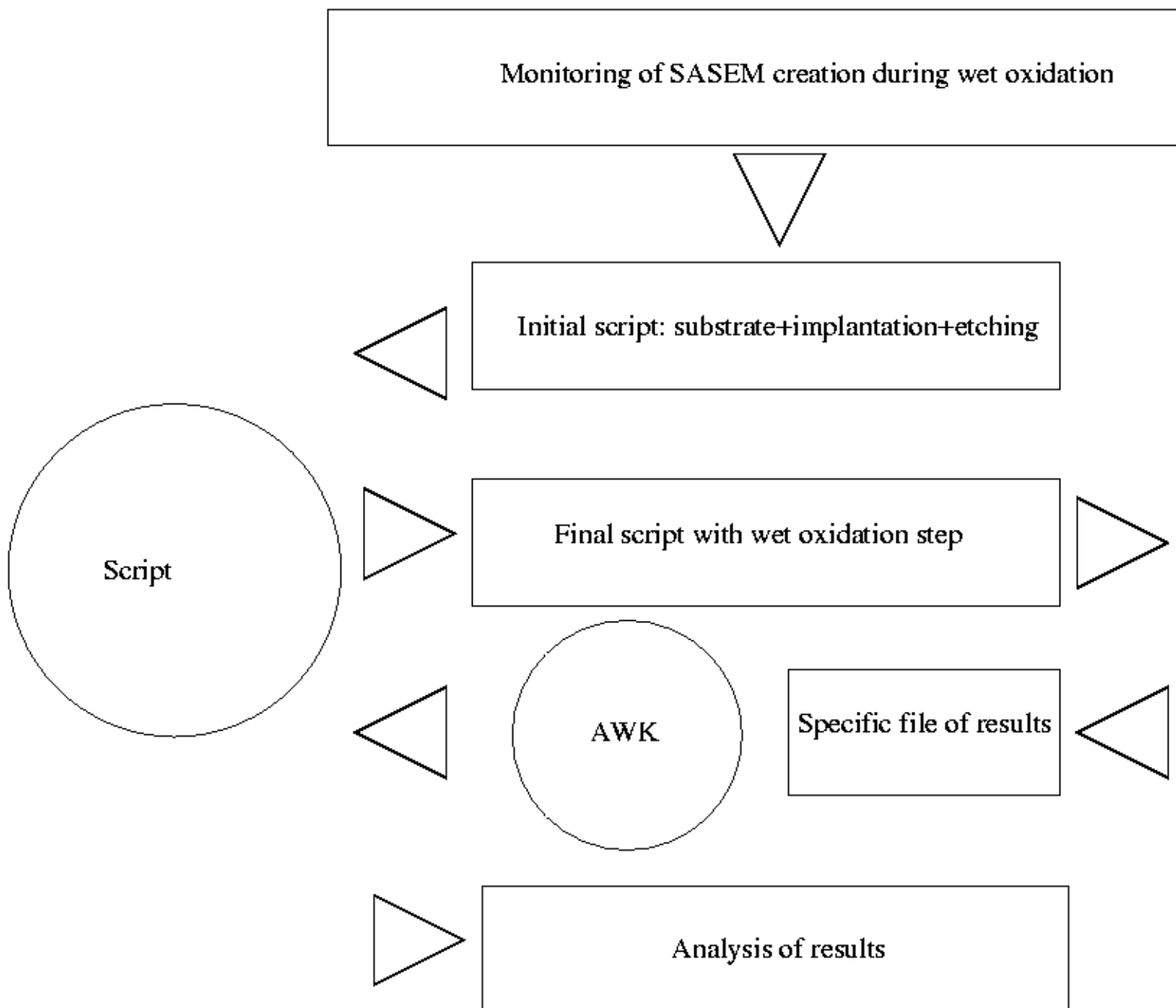
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Since the conventional floating gate device is believed to be hardly scalable below the 65-nm technology node, alternative storage structures for nonvolatile memories are strongly needed. The feasibility to make a silicon-on-insulator nano flash memory device based on the differential oxidation rate resulting from gradients in the arsenic doping concentration has previously been reported. The key processes involved in the fabrication are arsenic implantation, lithography and wet oxidation. The resulting device is a triangular MOSFET with a nanocrystal floating gate embedded in the gate oxide. Our objective is now to improve the reliability of the process and to ensure the presence of the memory dot for various conditions. Furthermore, a clear understanding of the dot formation mechanisms and of the influence of self-limited oxidation effects on the final device should be undertaken. We investigate the wet oxidation step in details using the generalised stress-dependent Deal and Grove approach. The various geometrical parameters (e.g dot surface, dot-channel distance ...) of the nano-device have been simulated as a function of the oxidation temperature and the duration of this oxidation step. The time of oxidation is critical for the process reliability. We have shown that the dot shape and size is reduced by increasing the oxidation temperature. Furthermore, the temperature controls the difference between the time of oxidation necessary to create the dot and the time to consume it totally. Low temperature oxidation is then recommended in order to keep a reliable process. In a second part, we

study the influence of the nanowire width and shape on the final device, all the other process parameters (dose, oxidation temperature, time) being kept constant. Simulations show that the choice of the linewidth for the central region is of utmost importance. We clearly confirm the experimental results showing the existence of two critical line widths that determine the creation or the consumption of the dot. In the linewidth range where the dot is created, the dot geometry changes and the dot radius is shown to linearly scale down. This results means that the properties of the SASEM device could be changed by a small variation in the central region. Finally, we study the influence of the shape of the nanowire before the oxidation step. Due to the high arsenic dose, overetching effects occur in the region of interest through electrostatic influence. This effect is beneficial for the assumed dimension in the central region (120 nm) and the dot is more easily separated in this case. However for lower dimensions of the SASEM device, this effect might be more problematic. To conclude, we stress that the optimisation of the arsenic dose is of crucial interest to study the down-scaling. The simulation of the scaling issues and the impact on the various process parameters are the next priorities.







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We first briefly summarize the fabrication and the resulting Self Aligned Single Electron Memory (SASEM). A SOI wafer with a 200 nm thick silicon overlay is used as a starting substrate. A high dose of Arsenic is implanted ($1 \times 10^{15} \text{cm}^{-2}$) to create a very localized and a very doped area. Since the oxidation rate is doping dependent [3, 4], it will be possible to realize an anisotropic oxidation. Next a thin oxide film and a nitride layer is deposited on the substrate. E-beam lithography and reactive ion etching is used to pattern the device. Figure 1 presents the layout of the device. The central part of the device consists of a 150 nm by 150 nm square. Two 100 nm wide constrictions are defined in order to realise the connection between the source and drain regions and the central part. The various dimensions are defined such as a dot can be created in the central part of the device and is separated from the source/drain regions. Finally, a wet oxidation step is performed in order to create the dot. Figure 2 shows a SEM photography of the central part where a nano-floating gate is observed on top of the channel.

PROCESS SIMULATION ENVIRONMENT.

The main steps of the SASEM process have been described and the most critical step is the wet oxidation since it governs the creation of the silicon dot on top of the channel. Oxidation is simulated by a standard DEAL and GROVE generalised viscoelastic approach [5, 6] using a commercial simulator [7]. We use the HO and PLUMMER model [3, 4] in order to describe the enhancement of the oxide growth rate through the arsenic dopants (anisotropic oxidation). We used a standard set of parameters for the oxidation model which is known to give reasonable results on various configurations [8]. Parameters are not so far from the standard parameters of the simulation tool[8]. The objective is not a get a perfect agreement by adjusting the parameters on a specific experimental configuration of the SASEM device but to give raisonnable and interesting trends. Moreover, we must keep in mind that this process is very complex to simulate since the refinement of the grid must be preserved during the oxidation and the diffusion and segregation of arsenic have to be correctly described. We start with an anisotropic grid with a very high level of refinement in the region of high doping where the dot is expected to be created. This condition is very important. If the mesh describing the dot geometry is very relaxed, the study of the evolution of the dot properties could be very problematic. To keep the quality of the initial grid during oxidation, very small timesteps are performed (inf than 1ms) in order to generate reduced and smooth adaptation of the grid. The main problem of the process simulation in general is the difficulty to access to specific geometrical information during the oxidation process. Furthermore, it is not fully adapted to the specificity of the SASEM memory cell. To overcome this problem, a monitoring tool has been developed. The flowchart of the different steps is presented in figure 3. The monitoring tool generates a complex script with a large amount of commands. The basic idea is to perform a spatial sampling of the shape of the MESA-structure during the oxidation step. After the process simulation, the monitoring tool is able to treat all the flow of data generated to access to the evolution of the various parameters (dot length, dot width, dot-channel distance ...). We will see that the coupling between the process simulator and the monitoring tool is very efficient and allows a broad range of simulations.

SIMULATIONS.

Example of shape monitoring.

Figure 4 presents an example of the monitoring of the silicon shape during a wet oxidation at 800°C. The silicon shape is represented for [0, 20, 40, 60, 80] minutes of wet oxidation. The profile for zero minute of wet oxidation is not strictly straight since a short dry oxidation step (2 minutes) is performed before the wet oxidation. As shown by the two figures, the oxidation is very fast in the region where the arsenic concentration is high (the maximum for the arsenic profile is located at 240 nm). The dot is created after 52 minutes in the configuration. As shown by the figure 4, the dot is consumed mostly at the bottom where the arsenic concentration is large. The top of the dot is clearly well protected by the nitride mask. In comparison, the bottom of the channel is clearly much oxidized.

Evolution of dimensional parameters.

Various parameters have been studied. We report here only the evolution of the dot properties (figure 5). The thickness at the dot creation is nearly the same $\sim 50\text{nm}$. This result indicates that the position of the maximum of the arsenic concentration governs the initial size of the silicon dot. There is a sharp decrease at the time of dot creation and next the dot size decreases almost linearly with a slope of about 0.5 nm/min . The evolution of the maximum dot width is also reported on the right figure.

Influence of the oxidation temperature on the final shape.

The evolution of the dot shape as a function of the oxidation temperature has been simulated. Figure 6 reports the evolution of both the channel and the dot shape. The time of oxidation for each temperature has been set just at dot creation. We clearly observe that the size of the dot is strongly reduced with an increasing temperature. In figure 6, the maximal half dot width is about 30 nm at 750°C and reduce to less than 10 nm for 950°C. For higher temperature, no dot is created. Furthermore, the oxidation temperature has clearly an impact on the shape that tends to be flat for a high temperature of oxidation.

This result indicates that the oxidation temperature has an important influence on the final structure and that a wet low oxidation temperature is recommended.

CONCLUSIONS

Only a short part of the simulations performed has been described here. Thanks to an extensive set of simulations, we have now access to the evolution of many parameters and evolutions which otherwise would have required many experiments. More understanding of the dot formation is the key to improve the process. To conclude, we stress that the optimisation of the process is of crucial interest in order to allow the downscaling of this alternative nano flash memory. The simulation and the definition of a strategy for scaling the device is the next step to adress.

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Figures

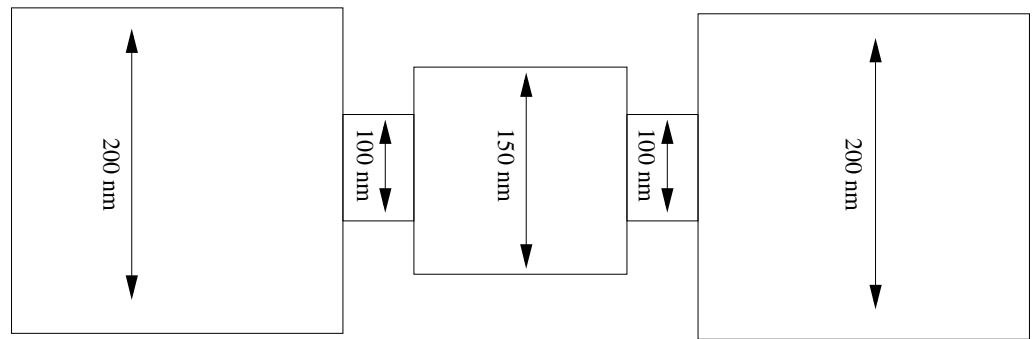


FIG. 1: Layout of the different regions of the SASEM device.

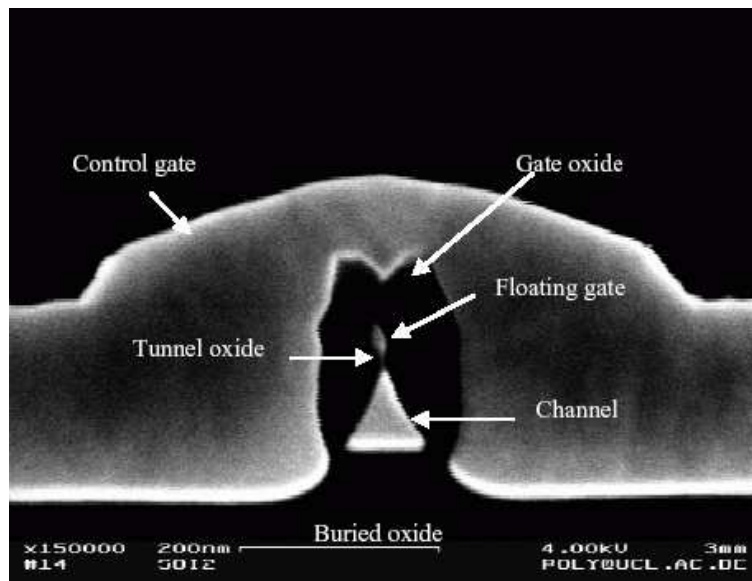


FIG. 2: SEM photograph of the central part of the nano-flash memory.

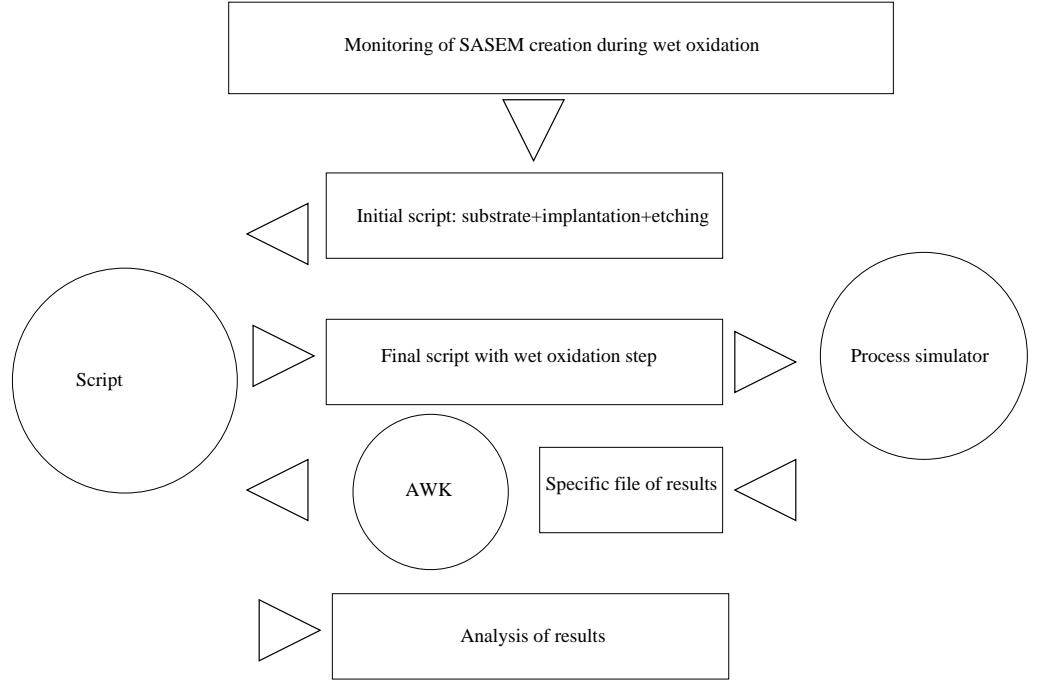


FIG. 3: Flowchart of the interaction between the monitoring tool and the process simulator.

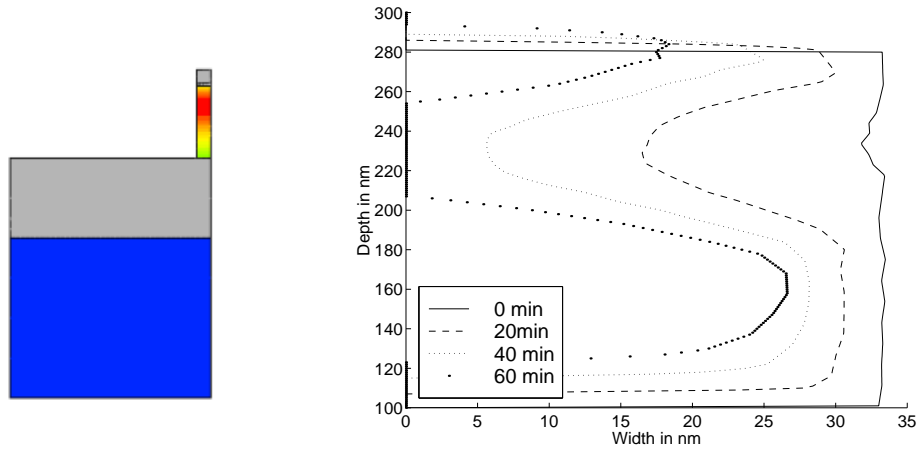


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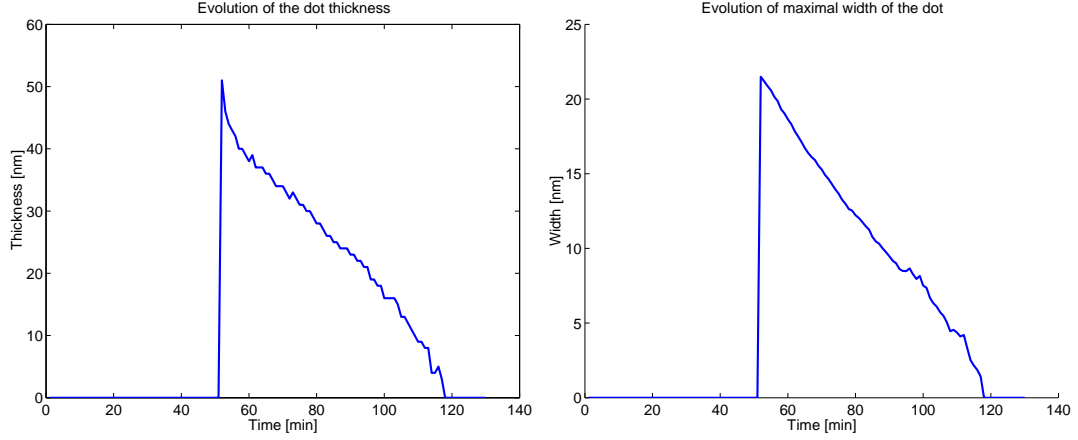


FIG. 5: (Left) Evolution of the thickness the dot during the wet oxidation step. The thickness is close to 50 nm at the creation time and decreases almost linearly with the duration of the oxidation step.(Right) Evolution of the maximal width of the dot.

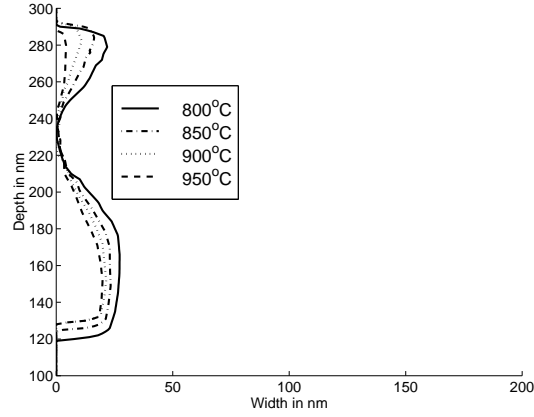
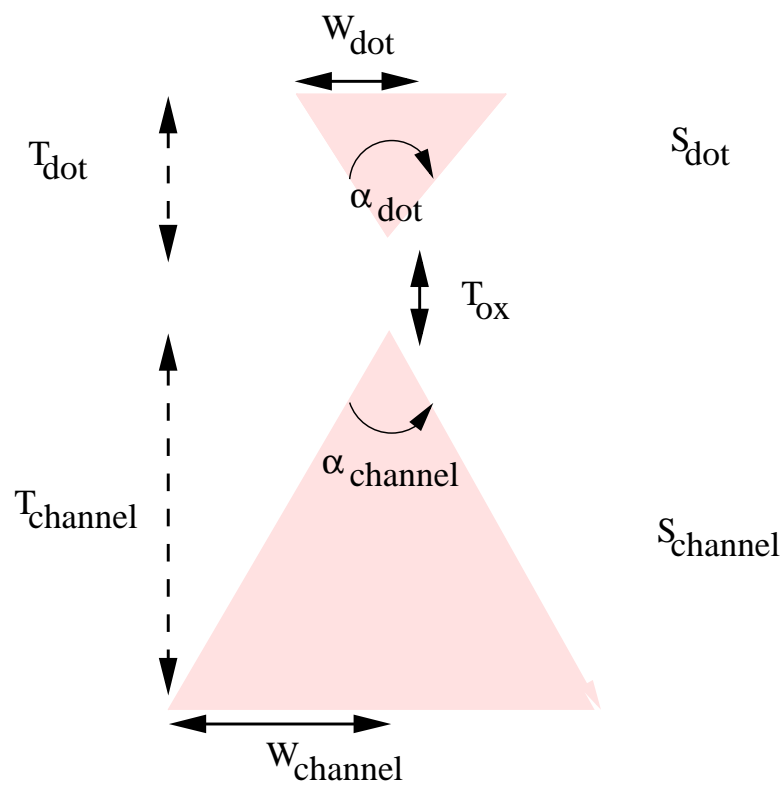
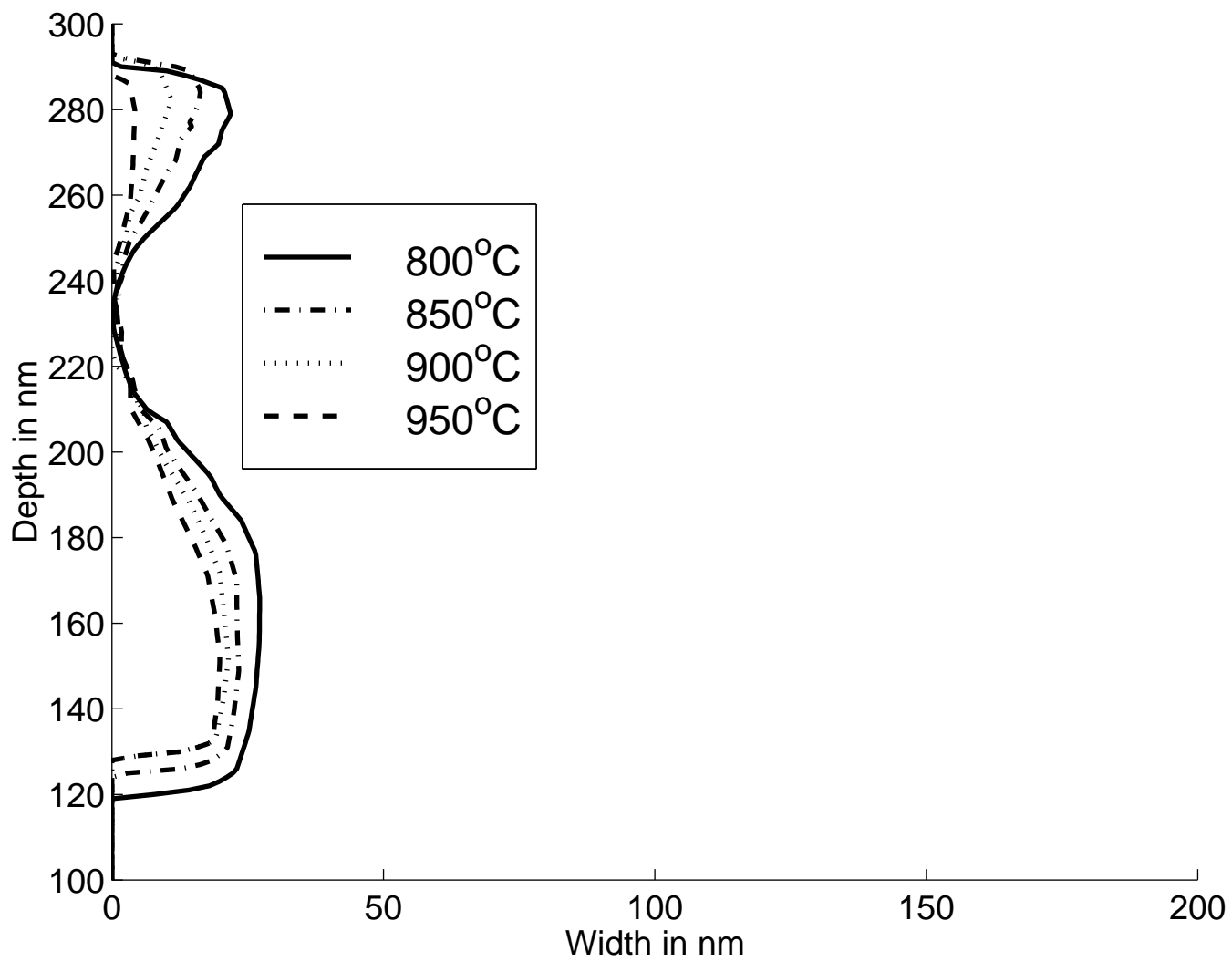


FIG. 6: Evolution of the MESA structure (only the silicon part) and for various oxidation temperatures. The time of oxidation is set at the dot creation time.



This figure "sasem.gif" is available in "gif" format from:

<http://arxiv.org/ps/1109.2927v1>



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Figures

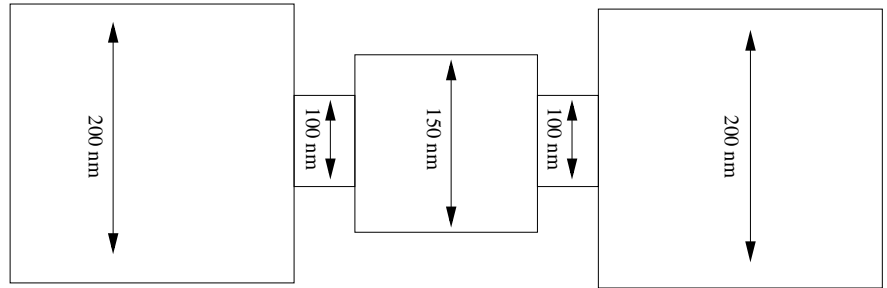


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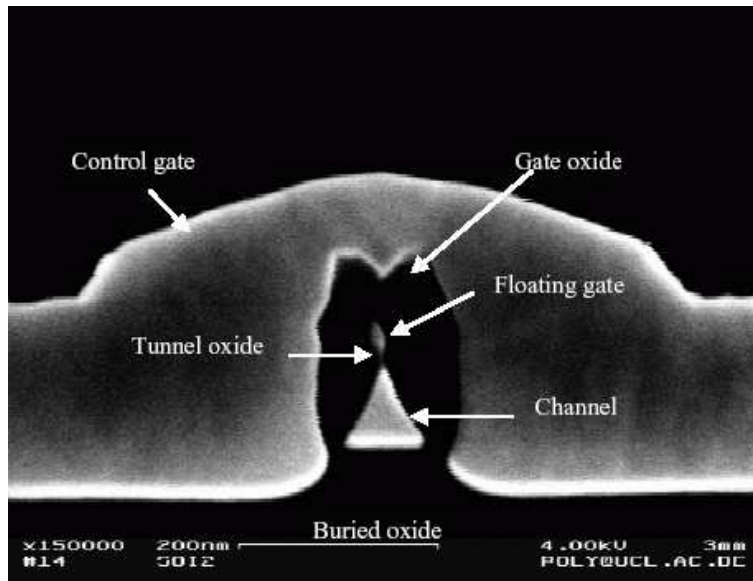


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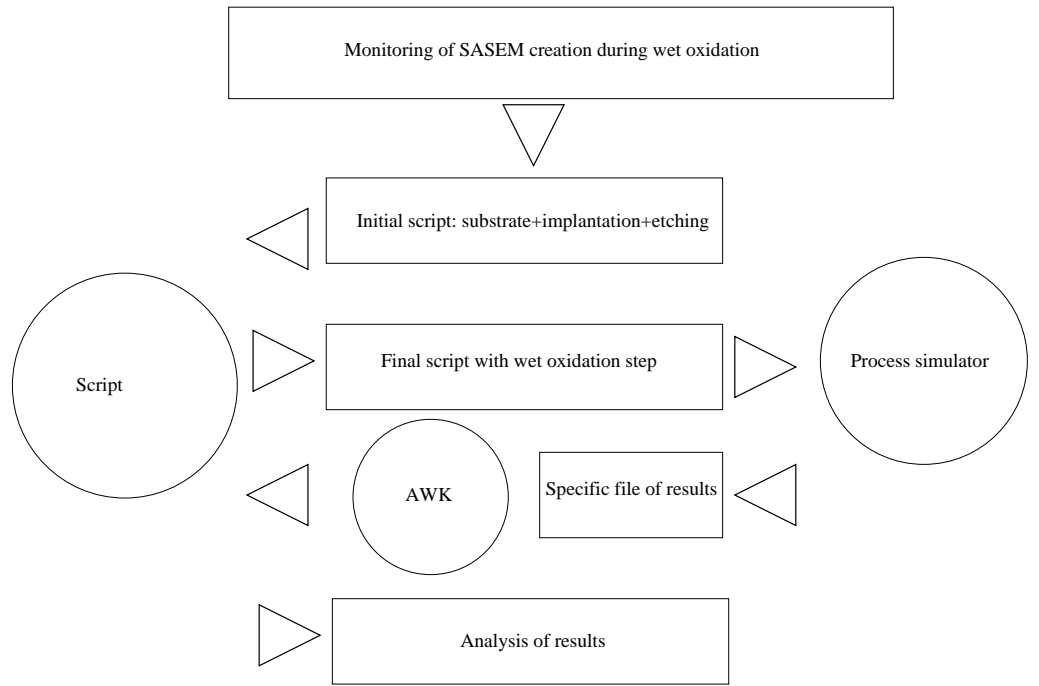


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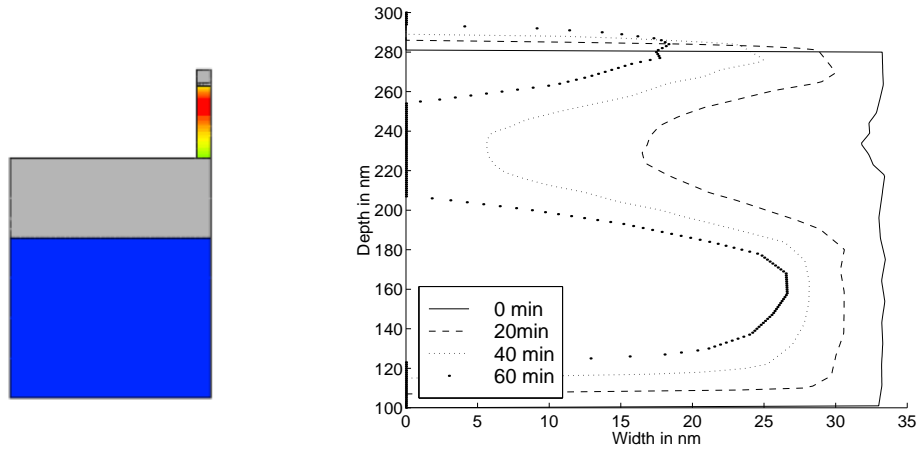


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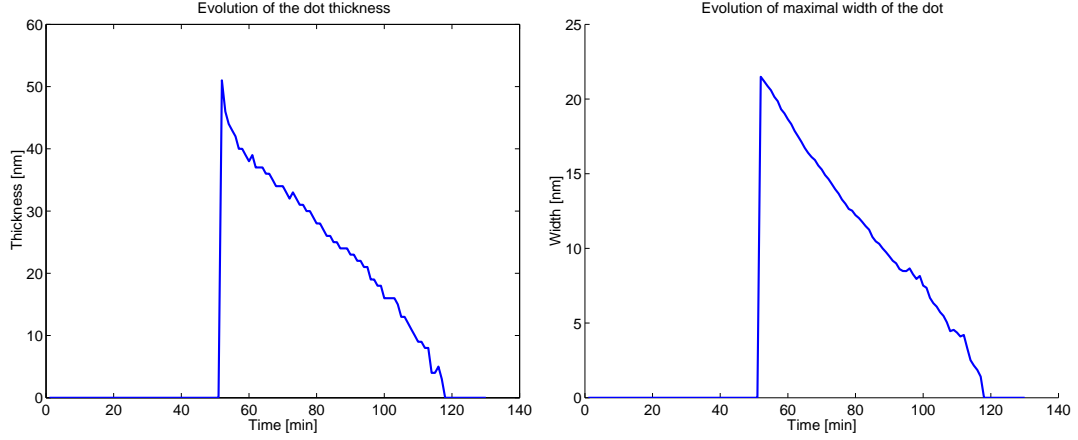


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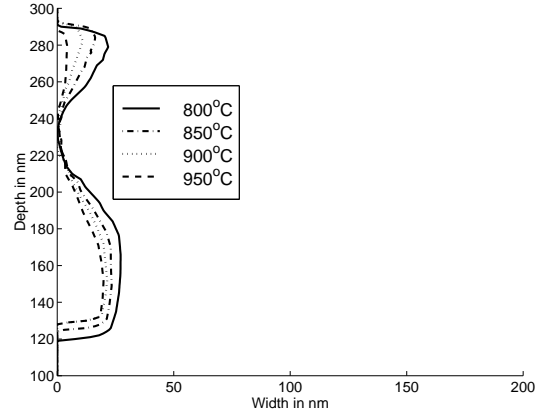


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